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WHITE PINE VIGOR – A NEW LOOK

RUSSELL T. GRAHAM

U.S. DEPARTMENT OF AGRICULTURE

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COVER PHOTO: Typical stands of mature western white pine of northern Idaho.

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RESEARCH SUMMARY

Matching the silvicultural system to stand condition is important in forestry operations. To assist the manager in making such matches, ranking of stands according to their vigor is often used. To evaluate stand vigor, individual tree vigor must be estimated. Two expressions of tree vigor are growth and mortality.

The vigor classes for mature western white pine were used to estimate periodic annual diameter growth, but no differences in diameter growth rate could be detected between the excellent, good, and fair vigor classes. The diameter growth rate of the poor vigor class is different from the other classes. Likewise using individual tree characteristics, crown ratio, crown class, and tip vigor, no better prediction of diameter growth rate could be achieved.

Mortality prediction may be accomplished using vigor classes or individual tree characteristics. The individual tree characteristics in the form of a prediction equation are more precise than the vigor classes. The predictions of mortality can be computed by using the equations or reading directly from mortality graphs.

Stand condition is important in estimating tree mortality. A tree in a poor vigor stand will have a larger probability of dying than the same tree in a good vigor stand. Cutting in a stand increases the probability of leave trees dying, unless the leave trees are of excellent vigor, those having long dense crowns.

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INTRODUCTION

Stand condition is the most important consideration when selecting a treatment alternative. Stand condition or stand vigor is the assimilation of individual tree condition or vigor. Tree vigor is some function of the growth rate of the tree and its length of life. To evaluate tree vigor, silviculturists have produced many different vigor classifications for different species. Dunning (1928) and Keen (1943) provided vigor ratings for ponderosa pine (*Pinus ponderosa* Laws.), Roe (1948) provided preliminary vigor ratings for western larch (*Larix occidentalis* Nutt.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.]), and Wellner (1952) developed a vigor rating system for mature western white pine (*Pinus monticola* Dougl.) All of these rating systems can and have been used to help select treatment alternatives for forest stands.

Wellner's method identified combinations of tree characteristics that defined four classes of tree vigor. The bounds for a characteristic within a class were defined intuitively. Then the overall rating scheme was evaluated by showing that the classes did, in fact, differ as to mortality and growth.

The white pine vigor classes do differ in mortality and growth, but how or by how much they differ has not been explored (Wellner and Boyd 1959). Wellner and Boyd's analysis showed differences in mean periodic annual diameter at breast height (d.b.h) growth but did not show which vigor classes were different from each other. They also did not show which tree characteristics within the vigor classes were important for mortality prediction and growth prediction, nor if stand vigor could be improved by partial cutting a mature stand of white pine.

From 1959 on, more analytical tools became available to evaluate tree growth and mortality. Hamilton and Edwards (1976) presented a procedure for analyzing individual tree mortality that could be used to estimate mortality by vigor classes or individual tree characteristics. Because of these recent developments and a rising interest in white pine management, another look is warranted into the vigor of mature white pine.

METHODS

Beginning in 1941, data were collected on white pine vigor and the impact of partial cutting on tree vigor. Between 1941 and 1954, 15 permanent, fixed-area sample plots were established throughout northern Idaho. These stands had a range of growing sites and species mixtures (table 1). The stands were even-aged ranging from 100 to over 200 years. The treated stands had partial cuts with the amount of white pine removed ranging from 15 to 68 percent. The plots were remeasured at or near 5-year intervals, with the length of records on the plots ranging from 5 to 20 years. The data collection resulted in 5,005 tree records with a variety of tree measurements and descriptions recorded (table 2).

Table 1.--*Western white pine partial cutting plot descriptions*[1]

Location	Use[2]	Plot no.	Year established	Treatment	Size		No. of white pine	Age	Years of record	Other species	Reproduction	Topography
					Acres	*Hectares*						
Idaho Panhandle National Forests												
Rapid Lightning Creek	F	183	1941	50% WP cut	6.02	2.41	285	100-120	20	GF,WH	C,WH	Lower east slope
	F	184	1941	None	6.72	2.69	723					
	V	185	1941	25% WP cut	4.90	1.96	348					
Stony Creek	V	194	1951	48% WP cut	10.00	4.00	188	180-200	10	DF,L	C,WH,AF	Steep west slope
Tango Creek	V	198	1954	40% WP cut	10.00	4.00	24	200+	11	GF,L	C,WH	Moderate to flat
Deception Creek	V	68	1941	15% WP cut	14.54	5.82	717	161-180	20	WH,GF	WH,GF	Mid northeast slope
	V	69	1941	None	14.00	5.60	848					
	F	70	1941	15% WP cut	5.95	2.38	253					
	F	71	1941	None	3.96	1.58	221					
Deception Creek	V	72	1942	Light cut	3.80	1.52	183	160-170	20	WH,GF	WH,GF	Mid south slope
	V	73	1942	None	3.81	1.52	52					
Deception Creek	V	82	1952	35% WP cut	10.00	4.00	149	180	10			Upper south slope
Steamboat Creek	F	77	1947	60% WP cut	9.60	3.84	349	140-180	10	L,DF,GF	GF,WH	Steep all aspects
Clearwater National Forest												
Swede Creek	F	500	1949	47% WP cut	8.00	3.20	161	140-160	5	GF,DF,L	C	Gentle west slope
Sheep Mountain Creek	F	501	1950	68% WP cut	10.00	4.00	504	120-140	9	GF,DF,L	C	All aspects
All plots					121.30	48.52	5,005					

[1]Species abbreviations: GF = *Abies grandis* (grand fir) L = *Larix occidentalis* (western larch) WH = *Tsuga heterophylla* (western hemlock) WP = *Pinus monticola* (western white pine) DF = *Pseudotsuga menziesii* (Douglas-fir)

[2]*F = used for fitting mortality models; V = used for verifying mortality models.*

Table 2.--*Measurements and observations taken on white pine partial cutting plots*

1. Diameter breast height
   a. Nearest 0.1 inch

2. Bole condition
   a. Rot
   b. Dead fork
   c. Broken top
   d. Successful beetle attack
   e. Unsuccessful beetle attack

*3. Crown class
   a. Dominant
   b. Codominant
   c. Intermediate
   d. Suppressed

4. Tip character
   a. Pointed
   b. Sprayed out
   c. Broken or dead

*5. Tip vigor
   a. Good
   b. Fair
   c. Poor

*6. Crown width
   a. Wide
   b. Medium
   c. Narrow

*7. Crown ratio
   In tenths of total height

8. Crown form
   a. Uniform
   b. Uniform - ragged
   c. One-sided
   d. Ragged, one-sided

*9. Crown color
   a. Green
   b. Light green
   c. Yellow

*10. Dieback
   a. Absent
   b. Moderate
   c. Extensive

*11. Crown density
   a. Good
   b. Fair
   c. Poor

12. Crown vigor rating
   a. Excellent
   b. Good
   c. Fair
   d. Poor

13. Cause of mortality
   a. Unknown
   b. Suppression
   c. Wind or snow
   d. Insects
   e. Disease
   f. Living

*Variables used by Wellner (1952) in his vigor classification for mature western white pine trees.

Six separate analytical procedures were used in the data analysis. For evaluating tree growth, analysis of variance, Tukey's multiple comparison procedure, regression, and F tests were used. For tree mortality, SCREEN, a computer program that identifies predictors of dichotomous dependent variables (Hamilton and Wendt 1975); RISK, a regression computer program for dichotomous independent variables (Hamilton 1974); and a chi-square test were used.

RESULTS: GROWTH PREDICTION

Vigor Classes

The vigor classes as defined by Wellner (1952) help distinguish differences among the mean annual diameter growths of the vigor classes. The diameter growth means are aligned with the excellent vigor class having the largest mean and the poor vigor class having the smallest mean (fig. 1). Using Tukey's multiple comparison test, the means of the excellent, good, and fair vigor classes were not different ($P \leq .05$). The poor vigor class mean is different from the other means.

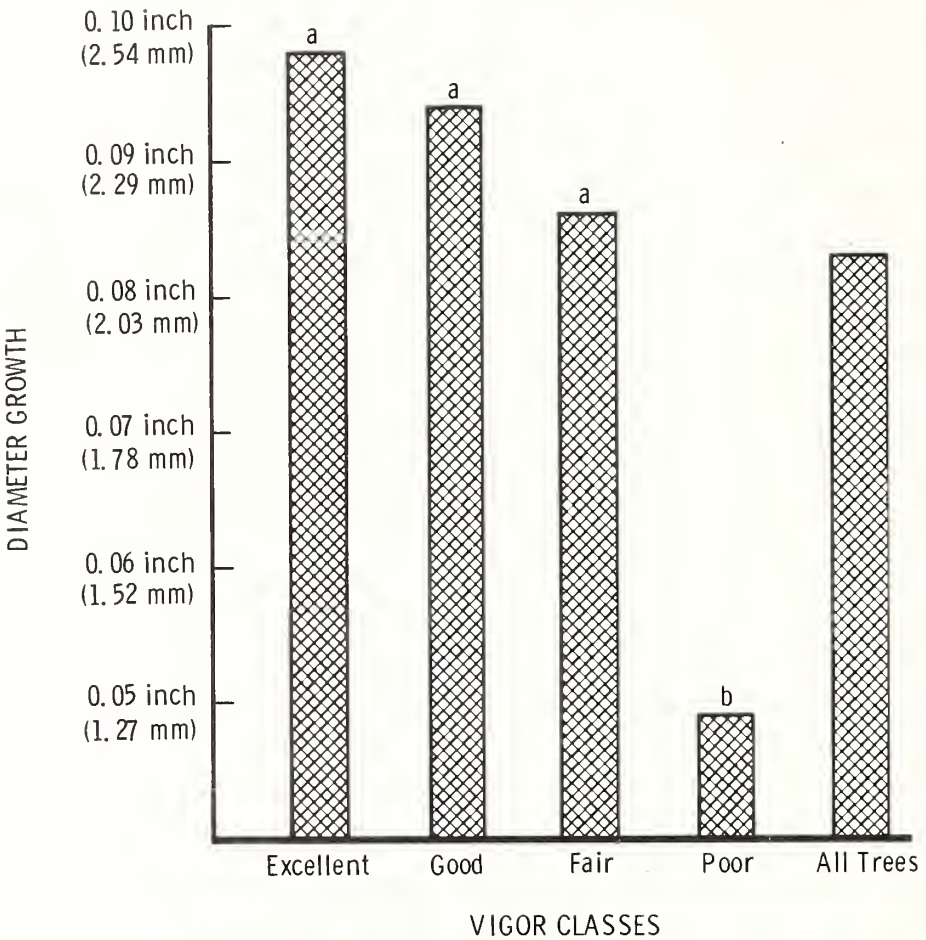

Figure 1.--Mean periodic annual diameter growth for western white pine. Different letters indicate significant differences ($P \leq .05$).

Prediction Equation

The diameter growth prediction equation was developed using a combination of regression procedures and F-tests. Various combinations of independent variables were tested in 4,095 separate regression equations with the largest R-square being 0.04. The best regression contained the following independent variables: crown ratio, tip vigor, crown class, crown density, and bole condition. Stepwise, crown ratio, tip vigor, and crown class continued to add significantly to the amount of explained variation in diameter growth. In contrast, crown density and bole condition did not add significantly to the explained variation. The most important predictors of diameter growth in mature white pine are crown ratio, crown class, and tip vigor. Therefore, a direct estimation of diameter growth by an equation provides some increase in precision compared to the four vigor class means, but the improvement is trivial in the face of a large component of unexplained variation.

RESULTS: MORTALITY PREDICTION

Vigor Classes

In both cut and uncut stands, vigor classes are good predictors of mortality. A regression using RISK was fit using annual mortality as the dependent variable and vigor classes as the independent variables on data from both uncut and cut stands. When both of these equations were tested on separate data using a chi-square test, no significant difference ($P \leq .05$) existed between the observed and predicted mortality. Annual mortality rates for cut stands by vigor classes were as follows: excellent 0.0030, good 0.0064, fair 0.0104, and poor 0.0159 (fig. 2).

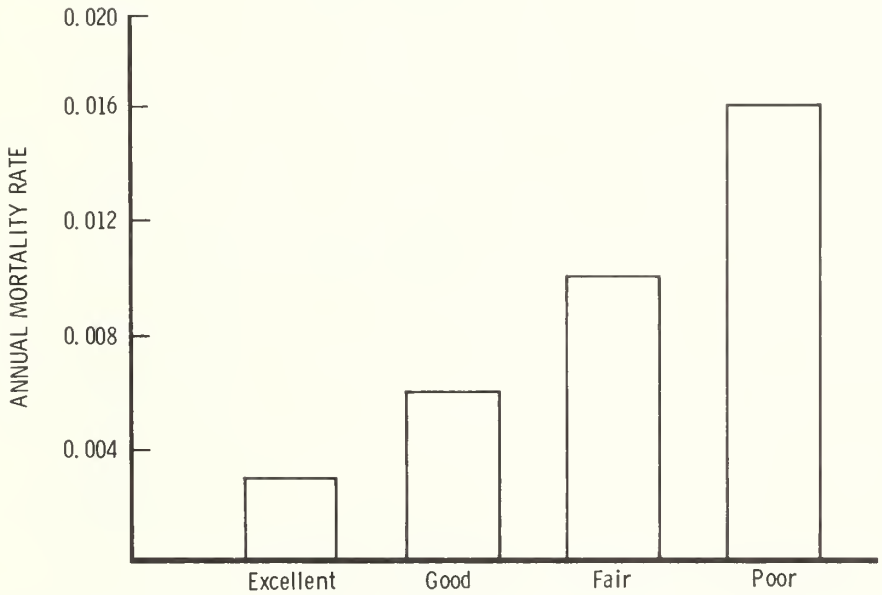

Figure 2.--Annual mortality rates by vigor class for cut stands.

To use the classes to predict mortality, the vigor of the tree must be determined using the vigor classification for mature white pine (Wellner 1952) (see appendix). After the vigor class is determined, annual mortality is determined using figure 2. This procedure provides a mortality rate for each vigor class--poor, fair, good, or excellent.

Prediction Equation

The significant ($P \leq .05$) predictors of mortality were identified using SCREEN. In both the cut and uncut plots, crown density and crown ratio were identified as signficant predictors of mortality. In the cut plots, crown ratio was the best predictor of mortality, with crown density the second best predictor for trees with crown ratios of 20 to 30 percent (fig. 3A). For the uncut plots, crown density was the best predictor of mortality (fig. 3B). For trees in uncut plots with good and fair crown densities, bole condition is the second best predictor. For trees in uncut plots having poor crown densities, crown ratio is the second best predictor of mortality. For the remaining subsets of trees, there were no variables that explained a significant additional amount of variation.

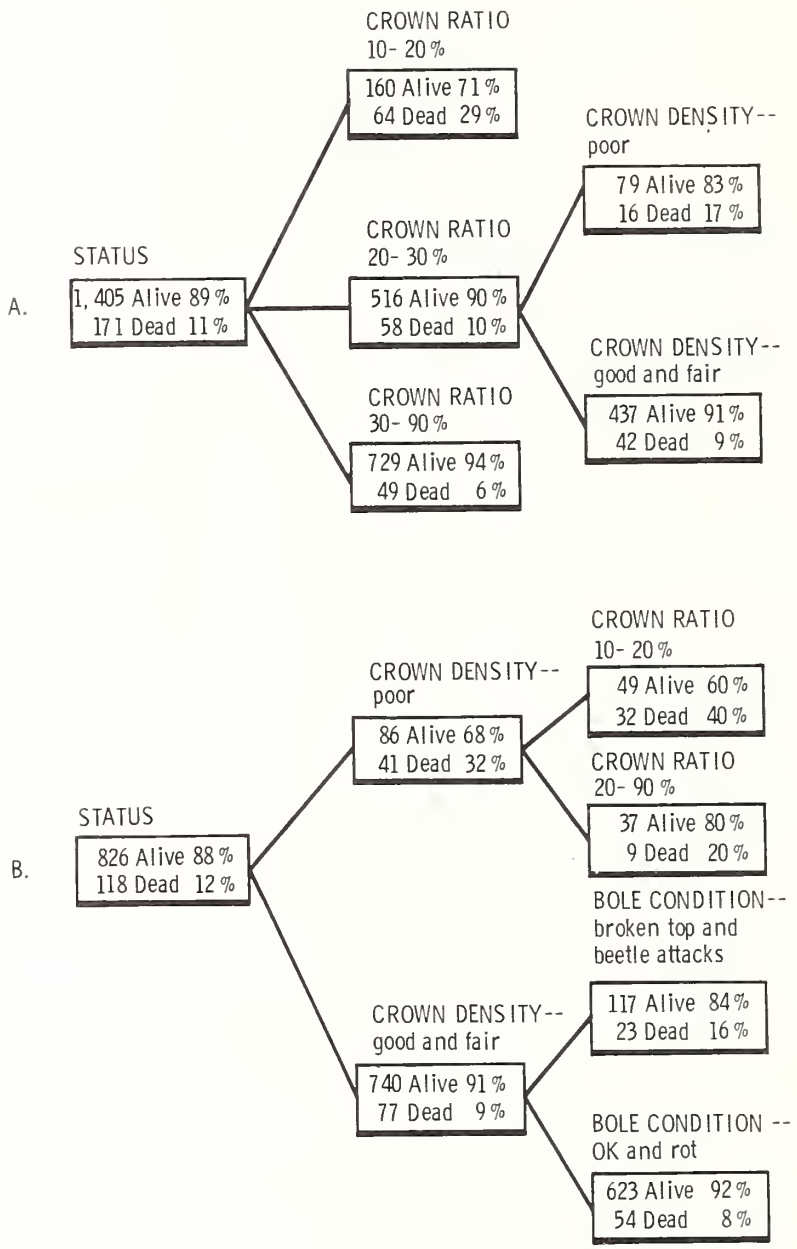

Figure 3A.--Probability of mortality of white pine in cut stands, 5 percent significant level. B. Probability of mortality of white pine in uncut stands, 5 percent significant level.

Using the above information, a mortality prediction model was fit, using RISK for the cut plot data. The model contained crown ratio and crown density as the independent variables. This prediction equation was tested on a separate data set using a chi-square test with no significant ($P \leq .05$) differences between the observed and predicted mortality. The model took the form:

$$P = 1 + \exp\left[-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3)\right]^{-1} \qquad [1]$$

where:

P = probability of mortality per year

X_1 = crown ratio in percent

X_2 = 1 if good crown density

X_2 = 0 if fair or poor crown density

X_3 = 1 if fair crown density

X_3 = 0 if poor or good crown density

$\beta_0 = -3.68381$ $\beta_1 = -.0136255$

$\beta_2 = -1.33584$ $\beta_3 = -.866748$

The prediction model was used to estimate the probability of mortality for each tree in the cut plots. These values were then averaged to obtain a mean probability of mortality for each cut plot. This average stand mortality rate was then evaluated as a potential predictor of individual tree mortality. Crown ratio, crown density, and average stand mortality were found to be the most important significant predictors of individual tree mortality. Using this information, another mortality model was fit using RISK. This procedure resulted in the following model:

$$P = 1 + \exp\left[-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4)\right]^{-1} \qquad [2]$$

where:

P = probability of mortality per year

X_1 = crown ratio as a percent

X_2 = 1 if good crown density

X_2 = 0 if fair or poor crown density

X_3 = 1 if fair crown density

X_3 = 0 if poor or good crown density

X_4 = Average stand mortality

$\beta_0 = -4.28115$ $\beta_1 = -0.0273056$

$\beta_2 = -0.594147$ $\beta_3 = -0.517882$

$\beta_4 = 108.005$

As before, this model was tested on separate data using a chi-square test with no significant ($P \leq .05$) differences between the observed and predicted mortality.

This equation can predict individual tree mortality as a function of crown density, crown ratio, and average stand mortality. Crown density can be estimated by comparing trees to a mature white pine crown classification (fig. 4). Crown ratio can be measured or estimated directly from the trees in question. Average stand mortality (ASM) can be computed directly using equation [1], and then averaging the individual tree mortality rates to get an average stand mortality rate. A less precise but adequate estimate of ASM can be estimated from the average stand crown ratio (fig. 5). Knowing a tree's crown density, crown ratio, and the average condition of the stand, the probability of mortality of an individual tree can be estimated.

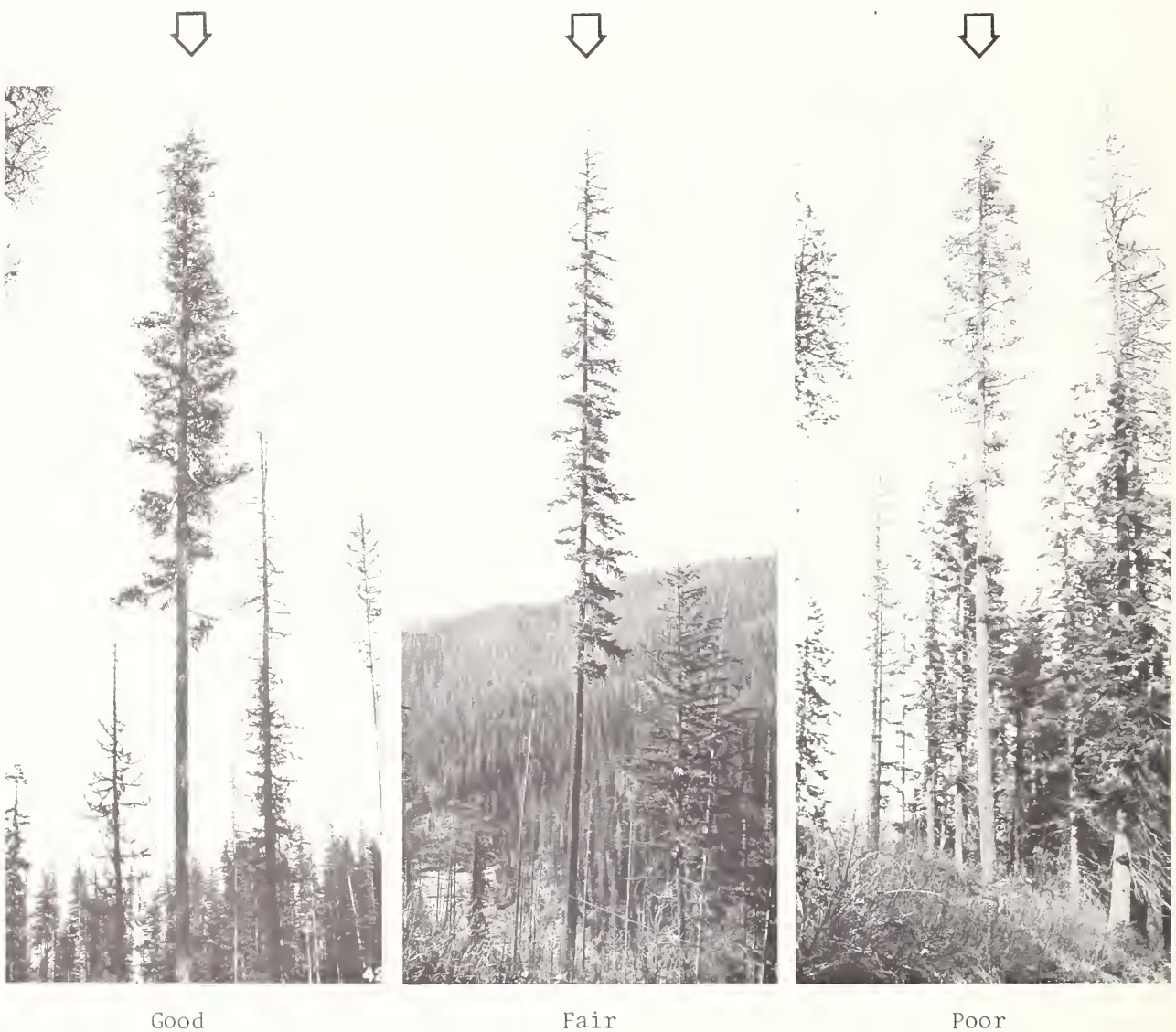

Figure 4.--Crown density classification for mature white pine.

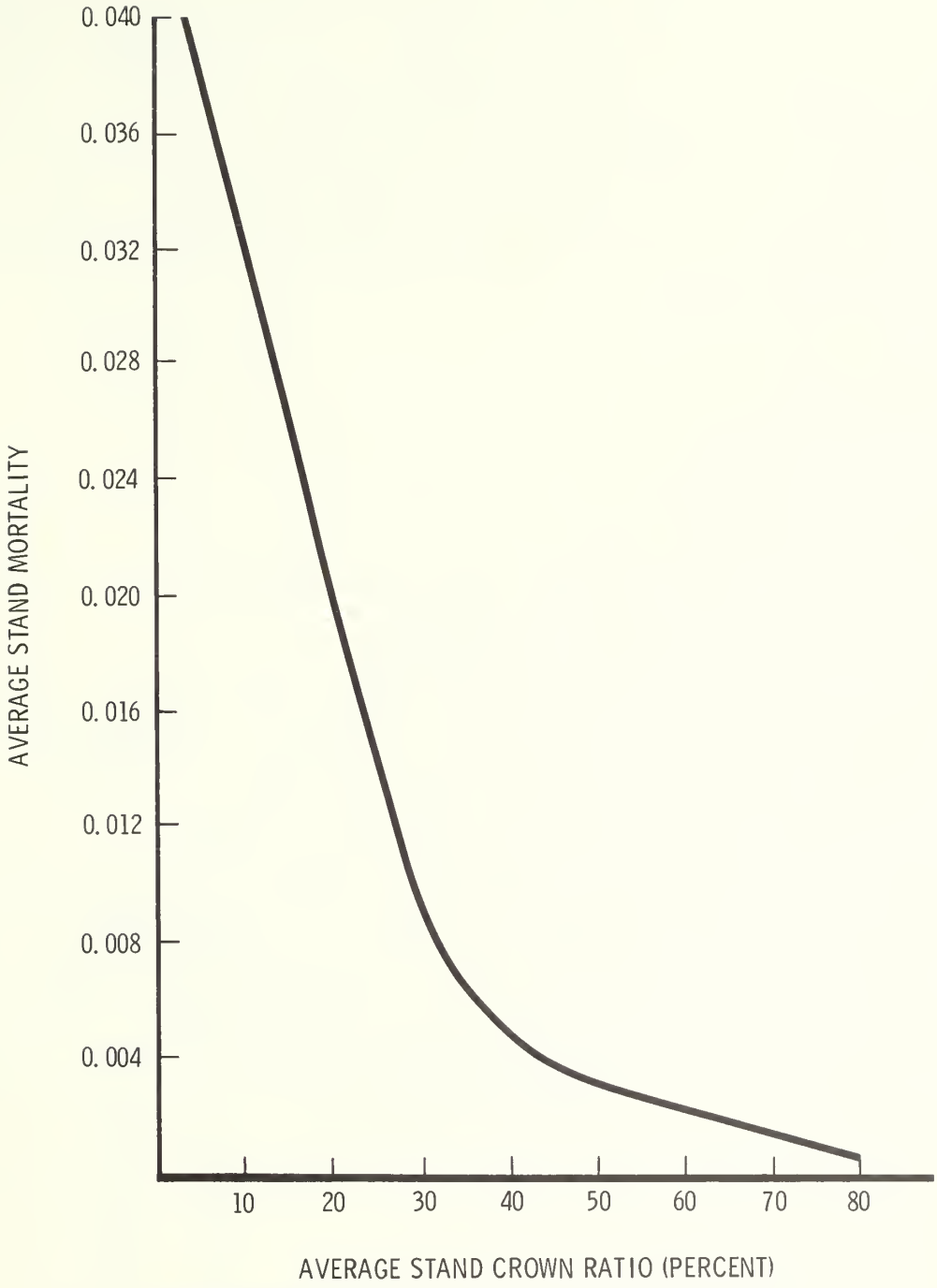

Figure 5.--Average stand mortality based on average stand crown ratio.

The final mortality model (equation [2]) can be used with the preceding information to estimate tree mortality rates. Often equations are difficult to use, so figures 6-8 show graphical solutions to the mortality model. To estimate mortality rates the graphs need an ASM, crown ratio, and crown density. For example, given a tree with a good crown density (fig. 4), a crown ratio of 50 percent growing in a stand with a mean crown ratio of 30 percent, the procedure would be as follows. Use the graph for trees with good crown densities (fig. 6). Using figure 5, the average stand mortality based on average stand crown ratio can be estimated. For the example, an average stand crown ratio of 30 percent yields a stand ASM of approximately .010. From figure 6, a tree with a crown ratio of 50 percent in a stand with an ASM of .010 would have an annual mortality rate of .006. The graphs or equations 1 and 2 can be used to compute annual mortality rates.

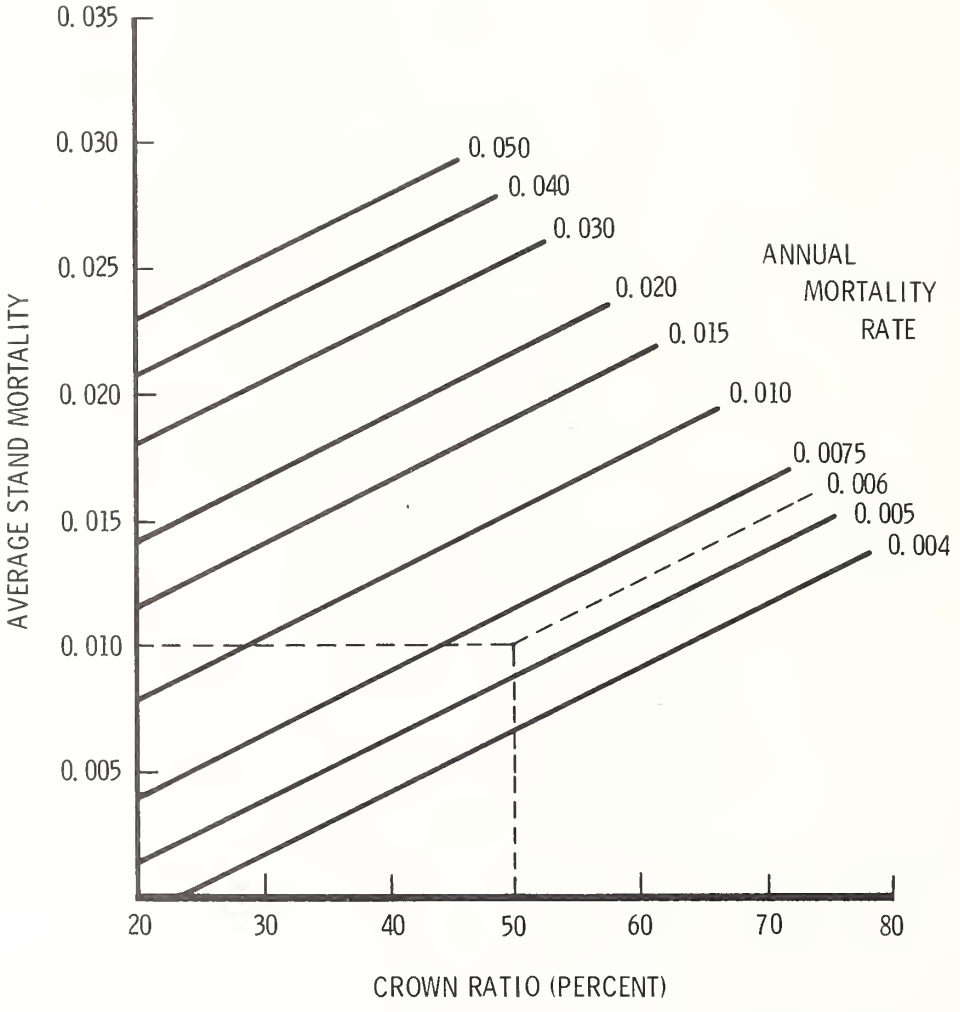

Figure 6.--Annual mortality rates for mature western white pine with good crown density for partially cut stands.

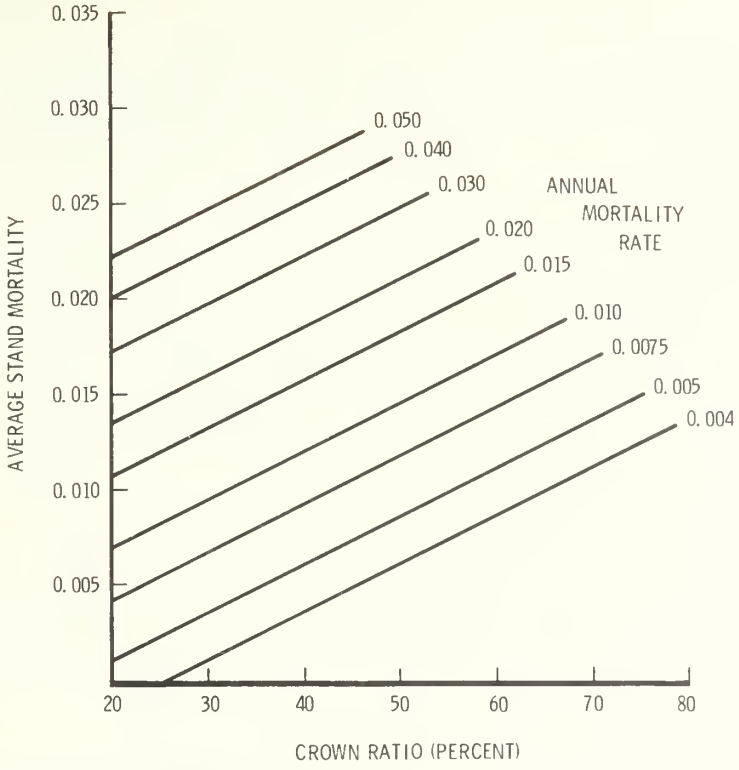

Figure 7.--Annual mortality rates for mature western white pine with fair crown density for partially cut stands.

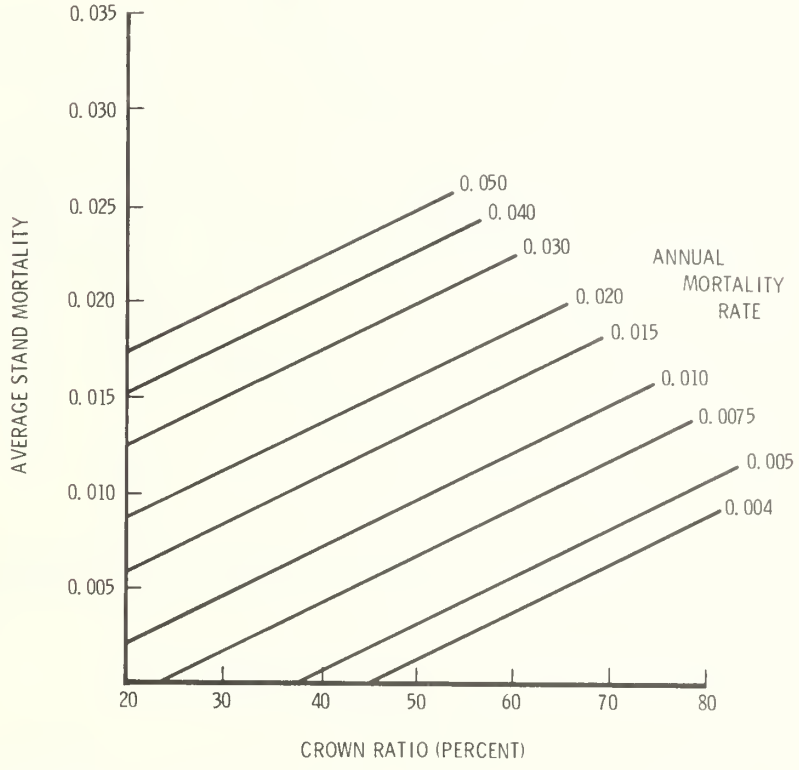

Figure 8.--Annual mortality rates for mature western white pine with poor crown density for partially cut stands.

Developing these mortality equations emphasizes the importance of stand condition. The probability of mortality of a tree of given characteristics increases as stand condition moves from good to poor. A tree with a crown ratio of 40 percent and a poor crown density in a stand with an ASM of .005 has a mortality rate of .0056, but in a stand with an ASM of .020 it has a mortality rate of .0357 (fig. 9). Similar results of a tree having a good crown density and a crown ratio of 60 percent are shown in figure 9.

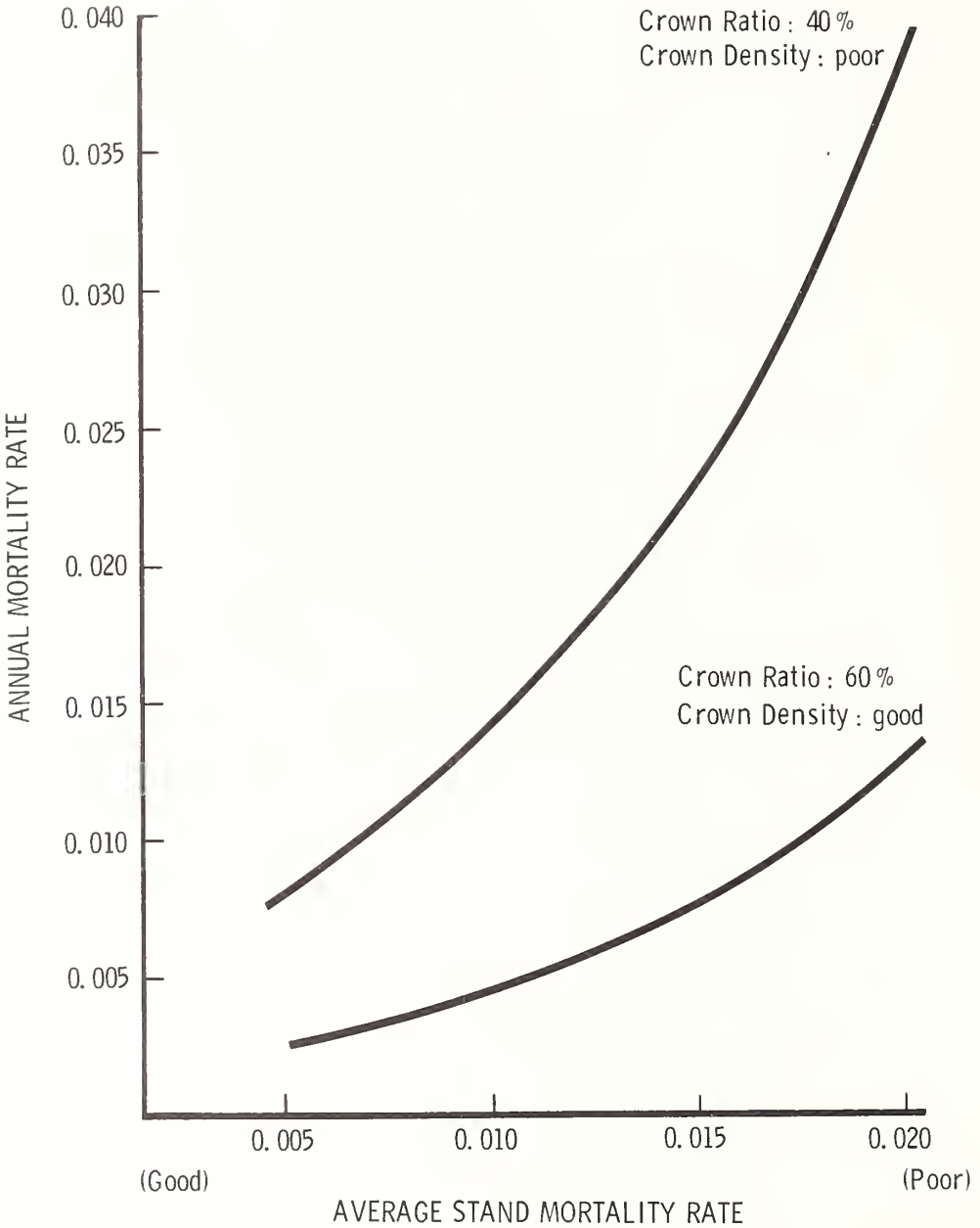

Figure 9.--Annual mortality rates of similar trees over a range of average stand mortality rates.

Using the same mortality model fitting procedures as before, two additional mortality models were fit for the uncut and cut data. Both models used crown density and crown ratio as the independent variables. Using a chi-square test on separate data, no significant ($P \leq .05$) differences existed between the observed and predicted mortality for either model.

The models for cut and uncut stands show the influence of cutting on individual tree mortality rates. A tree with a crown ratio of 20 percent and a poor crown density has a probability of mortality of .0188 in an uncut stand, and a probability of mortality of .0254 in a cut stand (fig. 10). As tree condition improves, cutting has less influence on mortality rates. A tree with a crown ratio of 70 percent and a good crown density, has mortality rate of .0026, and in a cut stand a mortality rate of .0020. Therefore, unless the tree is of excellent vigor, cutting will increase its probability of dying.

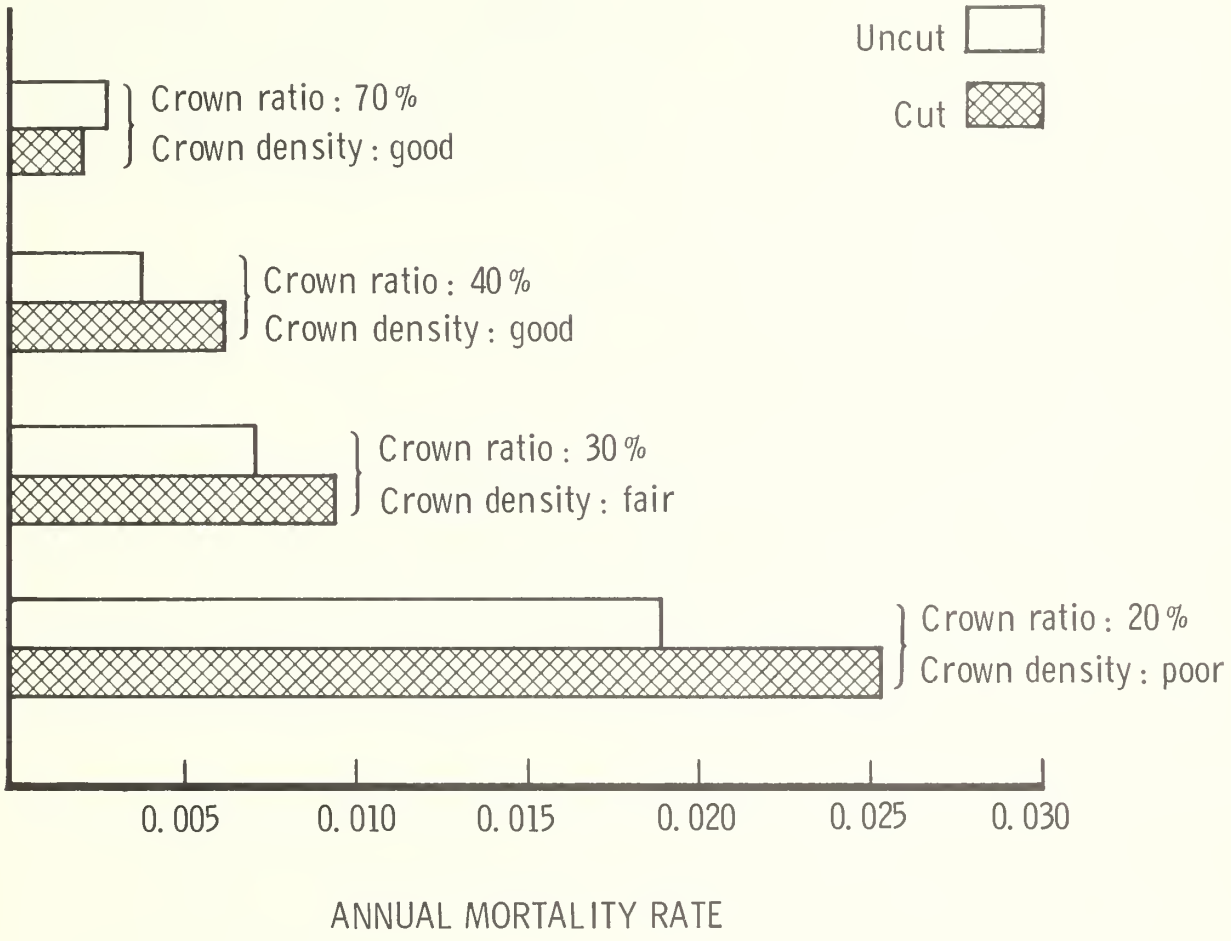

Figure 10.--Tree mortality rates in uncut and cut stands.

DISCUSSION

Stand vigor should always be considered when choosing stand treatment alternatives. This study provides a new look at white pine vigor ratings and some tools for evaluating individual tree mortality. A tree in a poor vigor stand will have a greater probability of dying than the same tree in a good vigor stand. When evaluating partial cutting, leaving just the best trees in the stand as leave trees may not be adequate if the stand is of poor vigor.

Likewise, cutting itself influences tree mortality. Only trees with long, dense crowns have less probability of dying in cutover stands than in uncut stands. All other trees with different combinations of crown length and crown density have a greater chance of dying in cut stands than uncut stands. Therefore, if a stand has no excellent vigor trees--that is, those with long, dense crowns--partial cutting in the stand will decrease the overall vigor of the stand.

The vigor of a stand is very important. Partial cutting places a stress on the leave trees, which in turn must be overcome by the vigor of the tree. Stands of good to excellent vigor are good choices for partial cutting. The trees chosen for leave trees should be of excellent quality. Only then is partial cutting going to increase the vigor of a stand of mature white pine. Mature stands of other tree species could also react to cutting as does mature white pine. Therefore, the vigor of a mature stand of timber should be carefully evaluated before applying a partial cut to the stand.

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APPENDIX

VIGOR CLASSIFICATION FOR MATURE[1] WESTERN WHITE PINE TREES

C. A. WELLNER[2]

CHARACTERISTICS[3]	VIGOR CLASSES			
	Excellent	Good	Fair	Poor
Crown class	Codominant	Codominant	Intermediate	Suppressed
Crown density	Good	Ordinarily good, occasionally fair	Ordinarily fair, occasionally poor, rarely good	Usually poor, occasionally fair, rarely good
Live crown Length in percent of total tree height	Long--usually 50 or more, 40 only if crown width is more than average	Average--30-50, 30 if of good density and average width; 40-50 if of fair density and and average width; more than 50 if good density and narrow	Short--20-30, 20-30 if of fair density and average width; 30 if of good density but narrow; over 30 if (A) average width and poor density or (B) narrow	Very short--20 or less, more than 20 if poor in other respects
Crown width	Average	Usually average, occasionally narrow	Usually narrow to average	Usually narrow to average
Crown color	Healthy green	Healthy green	Healthy green	Green or yellowish
Tip vigor[4]	Good	Fair to good	Poor to good	Usually poor to fair. If tip vigor and crown density are both poor, place in this class.
Dead branchlets or branches in upper crown	Infrequent	Sparse	Moderate frequency	Abundant

[1]Generally more than 100 years old.

[2]Formerly Chief (now retired), Division of Forest Management Research, Intermountain Forest and Range Experiment Station, USDA Forest Service, Ogden, Utah.

[3]Descriptions of characteristics for each vigor class generally state the lowest possible or limiting condition.

[4]Judge more by shoot elongation than by profile shape.

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Graham, Russell T.
1980. White pine vigor - a new look. USDA For. Serv. Res. Pap. INT-254, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Western white pine vigor classes are evaluated as potential predictors of diameter growth and individual tree mortality. The vigor classes were found to predict diameter growth poorly as did equations using combinations of tree characteristics. Both the vigor classes and mortality prediction equations are excellent methods of predicting mortality. Stand condition and stand treatments were both found to influence individual tree mortality. Tree mortality rates can be predicted using prediction equations or graphs.

KEYWORDS: Western white pine, mortality estimation, vigor classes, diameter growth

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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